объединенный
институт
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исследований
дубна

E2-89-867

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THE $q^2\bar{q}^2$ MESONS, $a_0(980)$, $f_0(975)$ AND QCD VACUUM

Submitted to "Modern of Physics Letters"

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1989

1 Introduction

Now there is an intriguing situation in the meson spectroscopy. In fact several mesons ($f_0(975), f_0(1400), f_0(1590)$) having the quantum numbers I=0, $J_I^P = 0^+$ are know [1]. In spite of the existence of the well-known $a_0(980)$ mesons, recently GAMS has reported about the discovery of a new resonance with the same quantum numbers $0^+(0^+)(I^G(J^P))$, and $m =$ 1300 MeV [2]. Thus, there are more then 9 mesons having $J^{PC} = 0^{++}$ in the energy region 1-1.6 GeV, which can't be classified as $q\bar{q}$ ground states.

There exist several points of view on the nature of $f_0(975), a_0(980)$ mesons. The $f_0(975)$ and $a_0(980)$ mass degeneration and the strong coupling of $f_0(975)$ with the $K\bar{K}$ channel make the explanation of these states in the simplest two-quark model difficult and probably indicate their exotic nature.

Earlier,different interpretations of these mesons as four-quark states $q^2\bar{q}^2$ [3] ,hybrids $q\bar{q}g$ [4] have been proposed and $f_0(975)$ has been considered as glueballs gg [5,6] or as a two-quark system with a glueball [7].

Four-quark mesons were studied in detail in the MIT model [3]. However the annihilation channels are of great importance for the spectroscopy of these states. Some time ago we proposed the quark model with the quark interaction through instanton exchange. This interaction is obviously not $U_A(1)$-invariant and gives a nonzero contribution to the annihilation channel.Thus, the $U_A(1)$ problem was solved in the quark model.Note that this mechanism of $U_A(1)$ symmetry violation explains the EMC data on measurement of the axial current matrix element over polarized nucleon states [8,9].In this paper, we study the four-quark states in the framework of that model, and as a result, a satisfactory description of the $f_0(975)$ and narrow $a_0(980)$ mesons as $q^2\bar{q}^2$ states is obtained.

2 Whether the $q^2\bar{q}^2$ mesons are the magically mixed states?

An analysis of the S-wave processes: $\pi\pi \to \pi\pi, \pi\pi \to K\bar{K}$ etc. reveals a significant coupling of $f_0(975)$ with $K\bar{K}$. The MIT model contradicts these facts because its physical states are magically mixed and such decay modes are impossible[3].Therefore in [10] the following mixing was proposed

$$\begin{aligned} f_0(975) &= C^s * \cos\alpha + C^0 * \sin\alpha \\ f_0(1400) &= C^s * \cos\beta + C^0 * \sin\beta \\ C^0 &= u\bar{u}d\bar{d} \\ C^s &= \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})s\bar{s} \ , \end{aligned} \tag{1}$$

where C^0 and C^s are the states, with respect to which the MIT hamiltonian is diagonal [3].It is natural to suppose that the reason of the mixing in (1) is the same as in the $\eta\eta'$ system.

3 The QCD vacuum effects in the quark model

For describing the $q^2\bar{q}^2$ spectrum we will use the quark model [11], in which the interaction between quarks is induced by the vacuum-fluctuation exchange and is nonperturbative. In this model the ideas of instanton nature of the spontaneous chiral symmetry breaking were used. Due to this there appear the dynamical mass of valence quarks, as a result of their interaction with the gluon and quark condensates , and strong splitting of the multiplets owing to the short-range interaction induced by instantons. As shown in [11], the hadron energy is a sum of the kinetic energies of quarks and their interactions:

$$E = \sum_i E_{i'}^{kin} + E_{vac} + E_g + E_{inst} \ . \tag{2}$$

Here

$$E_i^{kin} = ((\frac{\kappa_i}{R})^2 + m_i^2)^{1/2} \tag{3}$$

is the kinetic energy of a confined quark,

$$E_{vac} = \sum_i N_i A R^2 \tag{4}$$

is the energy of interaction with quark and gluon condesates,

$$E_g = \frac{\alpha_s}{R} \sum_{i \neq j} \mu_{ij} (\vec{\sigma}\lambda^a)_i (\vec{\sigma}\lambda^a)_j \tag{5}$$

is the one-gluon exchange,

$$E_{inst} = -\frac{4}{3}\pi^2 \frac{\rho_c^2}{R^3} \sum_{a,b}^{u,d,s} I_{a,b}(2/3 + 1/2\tau_a\tau_b)(1 + 3/32\lambda_a\lambda_b(1 + 3\vec{\sigma}_a\vec{\sigma}_b)) \tag{6}$$

is the quark interaction energy, which is approximated with 't Hooft's effective lagrangian [12] in the instanton liquid model.We choose the wave functions of the quark in a spherical bag as the confined quark ones. The model parameters are fixed in accordance with the hadron ground state spectrum $\alpha_s = 0.7, \rho_c = 2GeV^{-1}$ and are in agreement with the values,determined independently in the QCD sum rules and in the instanton liquid model.In distinction to the MIT model, the one-gluon term E_g (5) is practically non essential and all splittings are connected with the instanton term (6) [11].

4 $q^2\bar{q}^2$ mesons

In [13] a $q^2\bar{q}^2$ state spectrum was calculated. The instanton interaction (6) leads to the aromatic mixing of the states and it changes strongly the decays properties of $0^+(J^P)$ mesons.The width of $q^2\bar{q}^2$ resonance decay into two mesons is

$$\Gamma = \frac{g^2}{4\pi}\frac{1}{4\sqrt{s}}\rho, \rho = \sqrt{\frac{(s - m_+^2)^2(s - m_-^2)^2}{s}}, m_\pm = m_1 \pm m_2 \ , \tag{7}$$

where $g = g_0 A$, g_0 is the $q^2\bar{q}^2$ state coupling with two mesons, A is the amplitude of transformation of a four-quark resonance into two mesons. The values of the amplitudes A are given in tables 1 and 2. They are coefficients in the $q^2\bar{q}^2$-states decomposition in $(q\bar{q})(q\bar{q})$ mesons pairs. In [10] by an analysis of the $\pi\pi \to K\bar{K}$ scattering data it has been that $g^2_{f \to K\bar{K}}/4\pi = 2 - 4.5GeV^2$. In distinction to the MIT model we obtain [13] a nonzero coupling of $f_0(975)$ with the $\pi\pi$ channel (see table 1) and weak coupling with $\eta\eta$. On the basis of strong coupling of $f_0(975)$ with the $\eta\eta$ channel the predictions for $\pi^+\pi^- \to f_0(975) + ... \to \eta\eta$ reaction have been obtained [10]. The experimental investigation of this reaction may be a good test for these results.

Table 1

The amplitudes of $f_0(975), a_0(980)$ meson transformations into two $0^-(J^P)$ mesons

		A
a_0 $m_t = 1100$	K^+K^-	-0.29
	K^0K^0	0.29
	$\pi^0\eta$	0.05
	$\pi^0\eta'$	0.58
f_0 $m_t = 1100$	$\pi^+\pi^-$	-0.12
	$\pi^0\pi^0$	-0.085
	K^+K^-	0.425
	K^0K^0	0.425
	$\eta\eta$	0.09
	$\eta\eta'$	-0.12
	$\eta'\eta'$	0.33

Table 2

The amplitudes of $q^2\bar{q}^2$ meson into two 0^- or $1^-(J^P)$ mesons

$q^2\bar{q}^2$	$\pi^+\pi^-$	$\pi^0\pi^0$	$\eta\eta$	$\eta\eta'$	$\eta'\eta'$	K^+K^-	K^0K^0
I=0							
m=1350	-0.09	-0.06	0.12	0.055	-0.06	0.04	0.04
m=1700	0.047	0.033	0.02	0.013	0.022	-0.09	-0.09
	$\rho^+\rho^-$	$\rho^0\rho^0$	$\omega\omega$	$\omega\varphi$	$\varphi\varphi$	$K^{*+}K^{*-}$	$K^{*0}K^{*0}$
m=1350	0.47	0.33	-0.25	0.03	0.00	0.02	0.02
m=1700	-0.05	-0.04	0.29	0.29	-0.09	-0.46	0.02
	$K^+\pi^-$	$K^0\pi^0$	$K^0\eta$	$K^0\eta'$	$K^{*+}\rho^-$	$K^{*0}\rho^0$	$K^{*0}\omega$
I=1/2							
m=1550	-0.11	0.08	0.156	-0.01	0.44	-0.31	-0.33

There exist two points of view on the interpretation of the $a_0(980)$ resonance. In the standard approach, the $\pi\eta$ system spectrum of masses is described as a usual narrow resonance of the Breit-Wigner form, which is in accordance with its $q\bar{q}$ mesons interpretation. The other point of view is that the width $\Gamma_{a_0\to\pi\eta}$ is very large (400-500 MeV), and the narrow structure of $\pi\eta$ spectrum occurs as a threshold effect due to the strong influence of the $K\bar{K}$ channel. This approach corresponds to the $q^2\bar{q}^2$ system interpretation of the $a_0(980)$ resonance [10].

Our result is that $a_0(980)$ may be interpretated as a narrow resonance of the $q^2\bar{q}^2$ system. The $a_0(980)$ width dependence on parameter ρ_c^2 (6) at $g^2_{f_0\to K\bar{K}}/4\pi = 4.5GeV^2$ is shown in fig.1. There is also shown the scale of $\eta\eta'$- meson mixing angle corresponding to this value of ρ_c^2. Thus we can see that in the framework of this model accuracy $a_0(980)$ may be interpreted as the narrow $q^2\bar{q}^2$-state resonance.

The data for other $0^+(J^P)$ states which can be observed in the experiment are given in table 2.

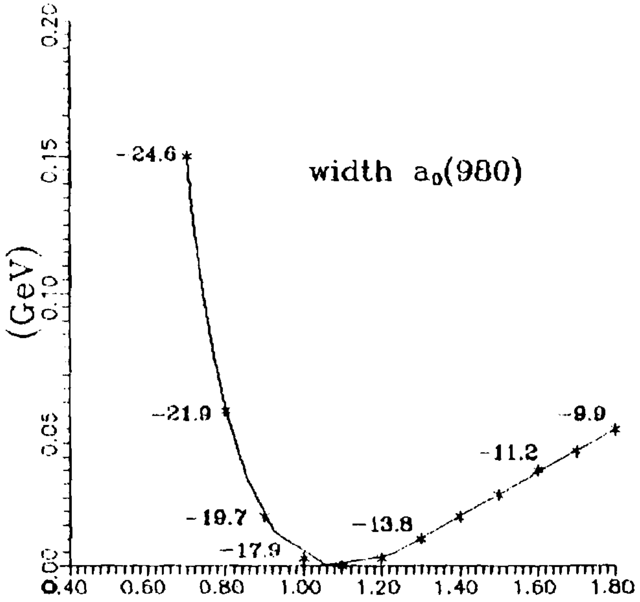

Fig. 1

We would like to express our deep gratitude to N.N.Achasov, P.N.Bogolubov for their support and permanent interest in this work and to S. B. Gerasimov, A. B. Govorkov, M. A. Ivanov, Yu. S. Surovtsev, M. K. Volkov for useful discussions.

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Received by Publishing Department
on December 26, 1989.

Дорохов А.Е., Кочелев Н.И., Зубов Ю.А. E2-89-867
$q^2\bar{q}^2$-мезоны, $a_0(980)$, $f_0(975)$ и вакуум КХД

В кварковой модели рассчитан спектр $q^2\bar{q}^2$ мезонов с учетом вклада аннигиляционных каналов через инстантон. Дана интерпретация $f_0(975)$ и узкого $a_0(980)$ как четырехкварковых состояний.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1989

Dorokhov A.E., Kochelev N.I., Zubov Yu.A. E2-89-867
The $q^2\bar{q}^2$ Mesons, $a_0(980)$, $f_0(975)$ and QCD Vacuum

In the quark model the $q^2\bar{q}^2$ mesons spectrum with consideration of annihilation channels through instantons is calculated. The interpretation of $f_0(975)$ and narrow $a_0(980)$ mesons as four-quark states is given.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1989